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Rigid Foams Based on Albumin and Gambier Tannin (*Uncaria gambir* Roxb.)

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Gambier is one of the largest sources of condensed tannins in Indonesia which has the potential as a raw material for rigid foam. Environment friendly rigid foam can be made from a mixture of gambier tannin, albumin, pTSA and hexamine. The purpose of this study was to investigate how albumin preparation and gambier tannin extraction methods affect the quality of rigid foam. Albumin preparation was carried out by a fermentation process using *Rhizopus* sp. yeast and then drying using the pan drying and foam drying methods. Extraction was carried out by heating using a magnetic stirrer and microwave-assisted methods. Based on the results of the study, the best rigid foam is the rigid foam with a combination of pan drying and microwave assisted. This rigid foam has a high density, high compressive strength, low swelling degree, resulting in a denser and harder rigid foam and based on SEM test showed closed and open pores in the rigid foam with a pore size of around 60.47 µm.

Keywords: Secondary metabolites, hydrolyzed tannins, Maillard reaction, tannins extract.

INTRODUCTION

Gambier plants are among the plants with the potential to produce tannins. Tannins are active secondary metabolites with high molecular weights containing hydroxyl groups with the empirical formula $C_{72}H_{52}O_4$ (Brianchi et al., 2015). Based on their structure and chemical properties, tannins are divided into two types: hydrolyzed tannins and condensed tannins. Condensed tannins are produced through extraction processes such as maceration, heating, ultrasonication, soxhlet extraction, and microwave-assisted extraction. The extraction methods used in this study were heating and microwave-assisted extraction. This method was chosen because phenolic compounds dissolve more effectively under heat (Naima et al., 2015). The microwave-assisted method has the advantage of performing extraction in a short time and with high yields. Condensed tannins can be used in the health sector (Namira, 2021), leather tanning (Mutiar et al., 2019), particleboard adhesives (Dhawale et al., 2022), and rigid foam (Lacoste et al., 2015); (Efrina et al., 2019).

This study utilizes condensed tannins for the manufacture of rigid foam. The process of making rigid foam is influenced by several factors such as the influence of chemical mixtures and physical treatments (Li et al., 2012), the influence of rigid foam without formaldehyde (Pizzi et al., 2013), organic blowing agents (Li et al., 2013), without using blowing agents (Basso et al., 2013) and the influence of tannin concentration (Anova et al., 2021); (Efrina et al., 2019). In general, rigid foam is used for insulation, transportation, buildings, vehicles, and electronics. This study examines the effect of combining tannin extraction with albumin preparation on the resulting rigid foam. This study combines the meringue method with both albumin extraction and preparation. Researchers generally choose only one tannin extraction method. Furthermore, no studies have previously performed fermentation in the albumin preparation used to create rigid foam. The meringue method is performed by mechanically stirring at high speed. The process involves mixing albumin and tannin at high speed. The advantages of the meringue method are ease of use, rapid processing, cost-effectiveness, and the resulting rigid foam is comparable to conventional techniques (Szczurek et al., 2014).

Albumin is produced by drying egg whites to form a powder. Methods for drying egg whites include pan drying and foam drying (Efrina et al., 2019). Oven drying directly results in a Maillard reaction in the resulting albumin. This maillard

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reaction reduces the quality of the albumin (Arifin et al., 2023), thus affecting the quality of rigid foam. One way to prevent the Maillard reaction is to carry out a fermentation process before oven drying. Fermentation can be carried out with *Rhizopus* sp. yeast (Hertamawati & Muhammad, 2020). The purpose of this study was to investigate how albumin preparation methods and gambier tannin extraction affect the quality of rigid foam.

MATERIALS AND METHODS

***Materials*:** The raw materials used were pure dried gambier obtained from Mungka District, Lima Puluh Kota Regency, para-toluene sulfonic acid (pTSA) (65%, aq. soln) were used as acid catalyst, domestic chicken egg white, hexamine were used as hardeners and aquadest.

***Equipment*:** The equipment used was Samsung brand microwave, magnetic stirrer, analytical scales, oven, desicator, rotary evaporator, universal testing machine 100kN/10tf (UTM), and scanning electron microscope (SEM) Merk Carl Zeiss.

***Research design*:** The research data were analyzed using ANOVA statistics to evaluate the level of significance of the observed data. If significance was found at the 5% level, a further Duncan's Multiple Range Test (DMRT) was performed.

***Preparation of gambier extraction using microwave-assisted tannin*:** Dried gambier were ground and filtered until they passed a 100-mesh sieve. The material/solvent ratio was 1:20, and the power was 450 W for 3 minutes. They were then filtered using a vacuum pump (3/4 HP suction power), followed by evaporation with a rotary evaporator at 70°C and dried in an oven for 24 hours. They were then ground and filtered until they passed a 100-mesh sieve.

***Preparation of gambier extraction using heating tannin*:** Dried gambier were ground and then filtered until they passed a 100-mesh sieve. The heating method was carried out using a magnetic stirrer at 75°C for 100 minutes, with a material/solvent ratio of 1:20. Next, they were filtered using a vacuum pump, followed by evaporation using a rotary evaporator, and dried in an oven for 24 hours. The flakes were then ground and filtered until they passed a 100-mesh sieve.

***Preparation of albumin using pan drying method*:** Prepare 100 g of egg white, add 0.4% *Rhizopus* sp. yeast, and place in a 25.5 cm x 25.5 cm pan drying. Ferment for 24 hours under anaerobic conditions (using an airtight container). Next, dry the egg white in an oven at 65°C for ± 24 hours. Grind the egg white and filter until it passes through a 100-mesh sieve.

***Preparation of albumin using foam drying method*:** 100 g of egg white is beaten with a mixer for approximately 10 minutes at 300 rpm. Then, 0.8% *Rhizopus* sp. yeast is added to a 25.5 cm x 25.5 cm baking pan. Ferment for 24 hours under anaerobic conditions (using an airtight container). It is then dried in an oven at 65°C for approximately 24 hours. It is then ground and sieved until it passes through a 100-mesh sieve.

***Rigid foam preparation* (Lacoste et al., 2015):** 26 ml of distilled water was mixed with 8 g of albumin and stirred for 2 minutes until a homogeneous emulsion was formed, 8 g of hexamine and 1.5 g of pTSA were added, and stirred for another 3 minutes. The stirring speed was 300 rpm. The rigid foam was then placed in an oven at 75°C for approximately 2 hours. The rigid foam was prepared using various treatments.

Table 1. Combination of Treatments in the Manufacture of Rigid Foam.

Albumin preparation method	Gambier extraction method	Mixing speed (rpm)
Foam drying	Microwave-assisted	300
Pan drying	Microwave-assisted	300
Foam drying	Heating	300
Pan drying	Heating	300

***Rigid foam characterization*:** Observations in the study included density (Lacoste et al., 2015), compressive strength (Lacoste et al., 2015), swelling degree (Amran et al., 2021), pore size and rigid foam morphology using a Carl Zeiss scanning electron microscope at 20 µm magnification, and climate chamber observations.

RESULTS AND DISCUSSION

***Density*:** The results of measuring the density of rigid foam from the combination of albumin preparation methods (foam drying and pan drying) and gambier extraction methods (microwave-assisted and heating) are presented in Table 2.

Table 2. Rigid Foam Density Test Results Data.

Albumin preparation method	Gambier extraction method	Density (g/cm^3)
Foam drying	Microwave-assisted	0,505 [a]
Pan drying	Microwave-assisted	0,579 [a]
Foam drying	Heating	0,415 [a]
Pan drying	Heating	0,439 [a]

Based on the statistical analysis of ANOVA, it shows that the density value with a combination of albumin preparation methods (foam drying and pan drying) and gambier extraction methods (microwave-assisted and heating) shows insignificant results. This shows that the albumin preparation method and gambier extraction method, statistically there is no difference in the density of the rigid foam produced. This shows that the density of rigid foam is influenced by other factors that do not directly depend on the method of albumin preparation or tannin extraction, such as the rigid foam microstructure, pore size, and foam stability during the formation and drying process.

These results are in line with the report (Jin et al., 2019) that increased density produces denser microporous rigid foam. (Efrina et al., 2025) and (Anova et al., 2021) reported that the interaction of the albumin method and gambier concentration showed no significant differences in the density of rigid foam but gave a significant variation in compressive strength. Density is also influenced by the type of tannin used, such as the study by (Lacoste et al., 2015) with the same treatment using spruce tannin resulting in a density of 0.417 g/cm³.

Table 2 shows that the combination of the pan drying and microwave-assisted extraction methods produced the highest density value, namely 0.579 g/cm³, while the combination of the foam drying and heating extraction methods produced the lowest density value, namely 0.415 g/cm³. This is because the pan drying method tends to produce rigid foam with a denser structure than the foam drying method. This is likely due to the more stable and even heating process in the pan drying method, so that the rate of gas cell formation is more controlled, reducing excessive expansion, and producing a denser rigid foam structure. Conversely, the foam drying method allows for greater foam expansion and the formation of larger and more porous cells, which reduces the density value.

Gambier extract obtained from microwave-assisted increases the viscosity of the solution, thereby inhibiting the expansion of CO_2 gas and causing the formation of a denser rigid foam structure. This is clearly seen in the combination of the pan drying method-microwave assisted which produces the highest density. (Magdalena., 2014) the combination of microwave-assisted power provides high yields and tannin levels. This is in line with (Fakhruzy et al., 2025) microwave-assisted produces high-quality tannin extracts that can increase viscosity and control foam drying expansion. (Ningsih & Rahayuningsih., 2019) microwave-assisted extraction (MAE) significantly increases the yield of total phenols and tannins in gambier leaves (*Uncaria gambir* var. Cubadak).

***Swelling degree*:** The data from the measurement results of the degree of development of rigid foam with a combination of albumin preparation methods (foam drying and pan drying) and gambier extraction methods (microwave-assisted and heating) are presented in Table 3.

Table 3. Results of the Rigid Foam Expansion Swelling Degree (%).

Albumin preparation method	Gambier extraction method	Swelling degree (%)
Foam drying	Microwave-assisted	36,91 [b]
Pan drying	Microwave-assisted	19,85 [c]
Foam drying	Heating	43,02 [a]
Pan drying	Heating	42,55 [a]

Based on the statistical analysis in Table 3, it shows that the degree of expansion of rigid foam with a combination of albumin preparation methods (foam drying and pan drying) and gambier extraction methods (microwave-assisted and heating) showed significant results. The foam drying method produced a higher degree of expansion, in both microwave-assisted extraction (36.91%) and heating (43.02%). This indicates that the foam drying method facilitates gas cell formation and greater volume expansion.

This is also in line with the basic principle of foaming, namely mixing air into a liquid matrix through a high aeration or agitation process, so that the foam volume increases significantly. According to (Borrero-López et al., 2022), the degree of foam development is influenced by the accuracy of the formula, such as the blowing agent, surfactant, stirring speed, and environmental conditions such as temperature and humidity, which determine the area of expansion formed and the rigid foam structure formed.

Table 3 shows the results of the rigid foam expansion test (%) for four treatment combinations. The highest value was shown by the foam drying-heating combination (43.02%), and the lowest by pan drying-microwave assisted (19.85%). However, the pan drying method showed a lower expansion rate, especially for the microwave-assisted extract (19.85%). This is because the pan drying method involves static heating on a pan, so there is no mechanical force to introduce air, and gas expansion is controlled thermally only, so gas cell growth is more limited.

The effect of the gambier extract with the heating method resulted in the highest degree of expansion in both foam formation methods. This may be due to the low viscosity of the solution, possibly due to the partial degradation of the active tannin compound during heating. Solutions with low viscosity tend to expand more easily, as there are fewer obstacles to the growth and expansion of gas cells. Conversely, microwave-assisted extraction produces a better chemical extract with a higher viscosity, as the tannin compound remains stable. This thicker solution tends to inhibit the formation of gas bubbles, thereby limiting the degree of expansion. This is in line with the theory proposed by Zhang et al. (2020), which states that high viscosity can inhibit the diffusion and expansion of CO_2 gas, resulting in smaller gas cells and less foam volume expansion.

The results of a study by (Link et al., 2011) stated that for rigid foam, the degree of expansion ranged between 10% and 60%, while research conducted by Anova et al. (2018) found the lowest degree of expansion at 54.90%. According to Szczurek et al. (2014), the degree of expansion of rigid foam is influenced by the density test value. A high density test will result in a low degree of expansion.

***Compressive strength*:** The results of the rigid foam compressive strength test are presented in Table 4.

Table 4. Rigid Foam Compressive Strength Test Results (MPa).

Albumin preparation method	Gambier extraction method	Compressive strength (MPa)
Foam drying	Microwave-assisted	8.856 [a]
Pan drying	Microwave-assisted	9.607 [a]
Foam drying	Heating	7.504 [a]
Pan drying	Heating	8.154 [a]

Based on the statistical analysis of ANOVA, it shows that the compressive strength value with a combination of albumin preparation methods (foam drying and pan drying) and gambier extraction methods (microwave-assisted and heating) shows insignificant results. The results of the study (Efrina et al., 2025) stated that the albumin preparation method and gambier extract concentration did not affect the compressive strength value of rigid foam. Compressive strength is one of the important mechanical parameters to evaluate the ability of rigid foam material to withstand compressive forces without damage.

Based on the data in Table 4, the compressive strength values ranged from 7.504 MPa to 9.607 MPa. The combination of pan drying and microwave-assisted extraction methods produced the highest compressive strength of 9.607 MPa, while the combination of foam drying and heating extraction produced the lowest compressive strength of 7.504 MPa. (Efrina et al., 2025) the treatment of 22g gambier extract + albumin foam drying produced a compressive strength of 4.68 kg/cm^2 or 0.458 MPa. However, statistically it also showed an insignificant effect on the compressive strength of rigid foam.

The pan drying method produces higher compressive strength values than the foam drying method, both in microwave-assisted and heating extracts. This is due to the characteristics of the pan drying method, which uses direct and relatively stable heating, so the foam compaction process is more controlled. This process produces a denser foam structure and smaller pores, which supports increased mechanical strength. However, the foam drying method, on the other hand, produces foam with a more porous structure and greater expansion, as shown in the previous degree of swelling data. Although it produces a lightweight foam, the large pores and thin cell walls cause a decrease in compressive strength due to reduced resistance to mechanical loads. (Zhang et al., 2020) found that reducing porosity or pore size increases strength through experimental tests and simulations.

The compressive strength value is also influenced by the gambier extraction method. Microwave-assisted extracts show higher compressive strength values compared to heated extracts, both in the foam drying and pan drying methods. This is related to the high viscosity of the solution due to the stability of active compounds, such as tannins, which are maintained during the microwave-assisted extraction process (Cañadas et al., 2023); (Fakhruzy et al., 2025). These active compounds play a role in increasing intermolecular bonds during foam cell wall formation, resulting in a more robust and strong structure. However, extracts from conventional heating tend to experience degradation of active compounds due to high temperature treatment and longer heating times. As a result, the resulting foam structure has a lower wall thickness, weak intermolecular strength, and reduced resistance to compressive forces.

The combination of pan drying and microwave-assisted extraction yielded the highest compressive strength, as the resulting rigid foam structure tended to be denser, more finely porous, and composed of cell walls reinforced by stable protein-tannin interactions. Conversely, the combination of foam drying and heat extraction yielded the lowest compressive strength, as the rigid foam structure was looser and less chemically and mechanically stable.

***Climate chamber*:** The climate chamber testing was conducted at room temperature of 27°C and 75% humidity. The rigid foam was immediately subjected to climate chamber testing to observe changes in the rigid foam over the seven days of observation. Observations were made to observe changes in color, texture, weight, and volume. The climate chamber test results are presented in Tables 5 and 6.

Rigid foam climate chamber testing was conducted to evaluate the dimensional stability and physical characteristics of albumin rigid foam under simulated extreme environmental conditions, namely high temperature and humidity. Observations were made for 7 days to assess the extent to which the foam maintained its structure, shape, and mechanical stability. Color changes were observed visually from day 1 to day 7. In general, all treatments experienced a gradual darkening of color, from light brown to dark brown. This change is likely caused by the Maillard reaction between residual albumin protein and tannin compounds due to high temperature and humidity. Overall, the observation results did not show any significant differences between methods, indicating that relative color stability is influenced by environmental conditions, not solely by the manufacturing or extraction treatment.

Based on the test, it was observed that the color of the rigid foam on day 1 was a slightly light brown, after day 3 the color of the rigid foam changed to a slightly dark and dark brown. Days 5 and 7 of observation the rigid foam changed color to dark brown. For the texture of the rigid foam on day 1, it was porous and slightly soft, day 3 it began to solidify, days 5 and 7 the rigid foam began to become hard. According to (Barszczewska-Rybarek et al., 2022) from the color observation of the rigid foam, there was a change in color from yellow to brown over time as a result of chemical oxidation and degradation of aromatic materials. Based on the texture, the longer the time, the rigid foam experienced degradation of the cell microstructure: the cell walls hardened so that the foam became denser.

Table 5. Climate Chamber Test Results: Rigid Foam Color Observation

	Albumin preparation	Gambir extraction	Day-			
			1	3	5	7
Colour	Foam drying	Microwave-assisted	Slightly light brown	Slightly dark brown	Dark brown	Dark brown
	Pan drying	Microwave-assisted	Slightly light brown	Slightly dark brown	Dark brown	Dark brown
	Foam drying	Heating	Slightly light brown	Dark brown	Dark brown	Dark brown
	Pan drying	Heating	Slightly light brown	Dark brown	Dark brown	Dark brown
Texture	Foam drying	Microwave-assisted	Porous and somewhat soft	Starting to get busy	Hard	Hard
	Pan drying	Microwave-assisted	Porous and somewhat soft	Starting to get busy	Hard	Hard
	Foam drying	Heating	Porous and somewhat soft	Starting to get busy	Hard	Hard
	Pan drying	Heating	Porous and somewhat soft	Starting to get busy	Hard	Hard

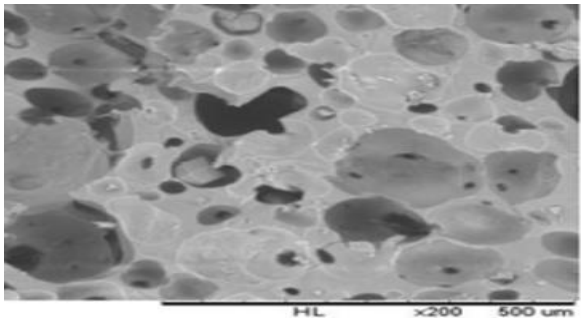
Table 6. Results of Climate Chamber Testing of Rigid Foam Weight and Volume

Observation	Albumin preparation method	Gambir extraction method	Day-			
			1	3	5	7
Heavy (g)	Foam drying	Microwave-assisted	29.140	28.375	26.735	26.62
	Pan drying	Microwave-assisted	26.940	26.863	26.540	26.295
	Foam drying	Heating	27.000	26.950	26.716	26.386
	Pan drying	Heating	27.290	27.226	26.826	26.506
Volume (cm^3)	Foam drying	Microwave-assisted	57.718	55.779	53.922	49.806
	Pan drying	Microwave-assisted	48.613	44.632	43.441	42.042
	Foam drying	Heating	67.690	51.813	51.437	50.143
	Pan drying	Heating	57.876	57.426	56.378	55.958

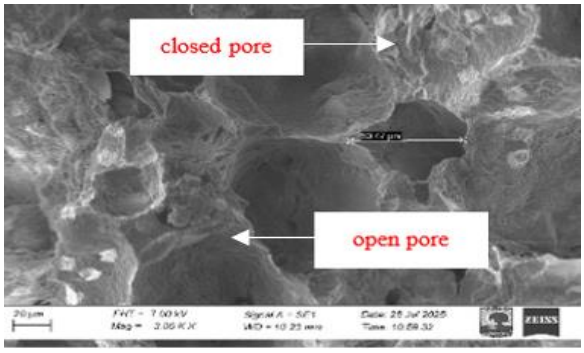
In general, all treatments experienced an increase in hardness and texture density from day 1 to day 7. On day 1: porous and somewhat soft, then on day 3: starting to solidify, while on days 5 and 7: hard. This indicates that the post-curing process in the climate chamber causes the rigid foam cell walls to tighten and reduces internal moisture. The foam drying treatment produced a more porous and soft initial texture than pan drying, but the difference narrowed after day 5, because all samples experienced similar hardening.

Weight loss occurred consistently in all samples for 7 days, indicating water evaporation. For observations of rigid foam weight on day 1, the average was 26.895 - 29.140 g, on day 3 the weight became an average of 26.810- 28.375 g, on day 5 the weight became an average of 26.430 - 26.826 g, on day 7 the weight became an average of 26.183 - 26.620 g. The results of the study showed a significant reduction in rigid foam weight on day 7. The largest weight loss occurred in microwave-assisted foam drying, indicating that the more open rigid foam structure and high initial viscosity allow for more water evaporation. In contrast, the pan drying method produces a denser structure, holding moisture better.

Observations for the volume of rigid foam also experienced a reduction, on day 1 the average volume of rigid foam was 48.613 g/cm^3- 67.690 g/cm3, on day 3 the average volume of rigid foam was 39.796 g/cm^3 - 63.051 g/cm^3, on day 5 the average volume of rigid foam was 38.488 g/cm^3 - 60.173 g/cm^3, on day 7 the average volume of rigid foam was 38.055 g/cm^3 - 59.315 g/cm^3. Based on these results, the volume of rigid foam decreased significantly on the 7th day of observation.



(1)



(2)

Figure 1. (1) Lacoste et al., (2015) and (2) pan drying-microwave-assisted.

The decrease in volume occurred in all treatments, but at different levels. According to (Barszczewska-Rybarek et al., 2022) from observations of rigid foam density, there was degradation of cell microstructure which was indicated by a

decrease in rigid foam weight so that the rigid foam became denser.

***Scanning electron microscope* (SEM):** SEM tests were conducted to observe the structure of rigid foam. The sample used was a pan drying-microwave assisted, the selection of this sample was based on the highest strength value.

The results of the SEM test observations in Figure 1 show differences in SEM results with the research of (Lacoste et al., 2015). The research of Lacoste et al. (2015) showed open and closed pores with large sizes, while in this study the number of pores is small with small sizes. Based on the results of the compressive strength test of Lacoste et al. (2015) research of 3.24 MPa, the pore size in this study was 9.607 MPa.

These results indicate that the pore size in this study tended to be smaller, thus affecting the compressive strength of rigid foam. The results also show that the section in Figure 1 shows open and closed pores. This may be influenced by the formation of polymers between tannin and albumin due to stirring, resulting in pores. Another factor is the pore filling by the residual reaction of hexamine and pTSA. The pore size in the study by Lacoste et al. (2015) resulted in a pore size of 160 µm, while in this study, the pore size was 60.47 µm. According to (Lacoste et al., 2015), high-density rigid foams have denser materials characterized by smaller pores.

***Conclusion*:** In this study, innovation lies in the influence of the albumin preparation method and the tannin extraction method on the characteristics of the rigid foam produced. rigid foam produced by the combination of the microwave-assisted pan drying method produces the best rigid foam. This result is based on the high density and excellent compressive strength, which is supported by the small pore size observed using SEM. The resulting rigid foam is environmentally friendly. The application of rigid foam resulting from this research is recommended for room insulation.

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***Ethical statement*:** N/A

***Availability of data*:** Data is available on request from the authors.

***Consent for publication*:** All authors submitted the consent to publish this research article in JGIAS**.**

***SDGs addressed*:** Industry, Innovation, and Infrastructure, Responsible Consumption and Production, Climate Action.

***Policy referred*:** Green Industry and Circular Economy Policy; UN Industrial Development Organization (UNIDO) Cleaner Production Program

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